

Chapter 13

Study of Urban Water Bodies in View of Potential for Micro-climatic Cooling and Natural Purification of Waste Water

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Abstract Urban wet lands and water bodies can reduce overheating of the urban environment as well their general function of natural water purification. Nonetheless, urban wetlands are either diminishing or contracted from their original shape and size due to pressures from the housing sector and unplanned urbanisation. This chapter presents the findings of a study investigating into the possible relationships existing between water quality of urban and peri-urban water bodies and three selected parameters; shape complexity, micro-climatic temperature and land use around water bodies. For this reason three urban and one peri-urban water bodies in Dhaka have been studied with regard to those four parameters. The study was conducted by both parametric techniques and field campaigns.

Keywords Urban water bodies • Micro-climatic cooling • Shape complexity • Housing sector • Water quality

13.1 Introduction

Anthropogenic activities causes build-up of Green House Gases (GHG) such as CO₂ and Methane, leading to increased global temperature. Spatially, cities are the highest centres of such anthropogenic activities and are major consumers of fossil fuels with over an 80 % of the global consumption. Given this, growing urban influence in consumption pattern and the need for local action as a way forward for securing global sustainable development was highlighted at the 1992 Rio Conference.

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199

Cities pose a significant field through which to address Climate Change (CC) as urban areas represent sites of high consumption of energy and production of waste. Dhaka being one of the most populated and polluted cities in the world, where the juxtaposition of wetlands and urban contexts have an opportunity for creating a viable and distinct character of its own. It has been reported that in the case of Dhaka during the summer months there exists a positive correlation between increased consumption of electrical energy and physiological stress and higher air temperature. Urban wet lands and water bodies have a role in balancing the overheating environment, even though they are either diminishing or contracted from their original shape and size due to pressures from housing sector and unplanned urbanisation in Dhaka. The edge of the water bodies are modified from their natural shape by filling. Further, in this modification process all the natural reed plants, which grow inside and at the edge of the water bodies, are removed which is evident from several urban water body development projects of Dhaka.

Natural wetland always acted as nature's own purification plant in the presence of different reed plant species i.e. Sedges, Rushes and Irises help to purify the waste water in a natural way by reducing COD content of water, oxygenation, elimination of pathogens, ammonium degradation, degradation of nitrate, removal of phosphates and heavy metal. The filling up and shape modification of the water body from their original shape greatly affects the urban micro-climatic cooling capacity and natural water purification potential. It is evident from several studies that water pollution of urban water body due to human induced land use correlated with the shape complexity of the water reservoir. Water bodies with simple geometric shape are always related with human induced land use whereas natural water bodies are mostly of complex geometric shape. Water bodies with a complex geometric shape can reduce the magnitude of water pollution. Urban land use also has a direct impact on the urban microclimate which results in Urban Heat Island Effect (Ahmed 1995). Urban water bodies can play an effective role in microclimatic cooling of the urban area. So in this context, the present research aims to investigate the relationships between the geometric shapes of urban wetlands, their water quality characteristics, urban microclimates and urban land use adjacent to wetlands.

13.2 Methodology

13.2.1 General

The study was conducted by both parametric techniques and field campaigns. Four Water bodies of Dhaka city were included in the study. Among the those four water bodies three are located in the main urban area and one is located in the fringe of Dhaka. The water bodies located in the main urban area are: HatirJheel lake, Banani (adjacent to Gulshan lake) and the Dhanmondi lake. The fourth water body named Alubdi lake is located at the fringe of Dhaka in the area named Mirpur. The three

water bodies located in the main urban area have gone under design intervention by professional planners and architects. The fourth water body at the fringe is not protected and the area of this water body is decreasing by continuous earth filling to extend housing area. In a study by Hwang et al. (2007) it was identified that "Urban land use within a watershed affects the water quality of the adjacent water reservoirs, and that the magnitude of this impact might depend on the shape complexity of the reservoirs". Their results also identified that human related land use is always associated with simple geometric shape of the water reservoirs, whereas the shape of the water reservoirs located in the area not effected by anthropogenic activities are mostly complex. Their study further showed that the shape complexity of a water reservoirs helps to counteract the negative impact of human induced land-use on the urban and peri-urban water bodies. It could be also observed from the study of Ahmed (1995) that urban land use has a direct impact on the urban microclimate which is resulting in Urban Heat Island Effect. From the study of environmental chemistry (Bunce 1991) it could be suggested that this hot urban environment impacts the water quality of urban wetland in a negative way. Dissolved oxygen is must for the existence of all aquatic life (Bunce 1991). Without sufficient oxygen in the water almost all the aquatic life in the water including fish will die. There are several reasons for oxygen depletion in water like thermal pollution, oxidisable substances in water from sewage, factory effluents, agricultural run-off etc., and decomposition of bio-mass like algal blooms (Bunce 1991). In high temperature oxidation will be faster and it is impossible for replenishment of oxygen from the air to keep pace with this depletion. So descriptors (indicators of organic matter) of the oxygen status of urban wetlands which will be taken in the research are Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD). The nutrient that will be considered in the research for the water quality analysis of the urban wetland is Total nitrogen (TN). Two other parameters that will be considered for water quality tests are faecal coliforms and Total Suspended Solids (TSS).

It could be inferred from the above study of literature that urban land use, urban micro climate and water quality of the urban wetland are interrelated. So in this context, the present research aims to investigate the relationship between the geometric shape of an urban wetland, its water quality characteristics, urban microclimate and urban land use adjacent to the wetland. The underlying rationale of this research is that urban and peri-urban wetlands can be considered as a basic unit of landscape "patch", whose shape complexity determines the characteristics of its edge. The permeability of edge controls the influx of pollutant into the wetland due to the surface water runoff. The characteristics of edge also determine the microclimatic cooling effect of the wetland. So the shape complexity of urban and peri-urban wetlands have unique effects on the relationship between the three parameters urban land-use type, urban micro climate and water quality characteristics of the urban wetland. Originality of this research is that effect of shape complexity of urban wetland on urban microclimate as a fourth parameter would be investigated besides its interrelationship to other two parameters urban land-use type and water quality characteristics of the urban wetland.

Based on the above discussion Four parameters have been identified as having an impact on the phenomenon discussed above i.e. shape of water body, water quality, land use and microclimate.

13.2.2 Shape Complexity

Shape complexity of the selected urban wetlands was measured using Fragstat software. One type of shape index based on perimeter-area relationships is the Fractal Dimension Index (FRAC). FRAC would be used to measure the shape complexity of urban wetland. As described in the Fragstat software manual “Benoit B. Mandelbrot (1977, 1982,) introduced the concept of fractal, a geometric form that exhibits structure at all spatial scales, and proposed a perimeter-area method to calculate the fractal dimension of natural planar shapes.” As per the Fragstat software manual FRAC equals two times the logarithm of patch perimeter (m) divided by the logarithm of patch area (m²); the perimeter is adjusted to correct for the raster bias in perimeter. The equation is given below:

$$\text{FRAC} = \frac{2 \ln(.25p_{ij})}{a_{ij}}$$

where p_{ij} = perimeter (m) of patch ij , and a_{ij} = area (m²) of patch ij .

A fractal dimension greater than one for a two-dimensional patch indicates a departure from a Euclidean geometry indicating an increase in shape complexity (McGarigal and Marks 1995). FRAC approaches 1 for shapes with very simple perimeters such as squares, and approaches 2 for shapes with highly convoluted, plane-filling (Mandelbrot 1982) perimeters. ESRI (Environmental Systems Research Institute) grid (Raster GIS file format) file of the shape of Urban Wetlands as an input for the Fragstat software was prepared by GIS software ARCMAP 10. Again the Autocad drawing file containing the shape information of urban wetlands was prepared with the help of google earth image. This Autocad drawing file was imported to ARCMAP 10 to prepare the ESRI grid file. In the Fragstat software FRAC value for the shape of each of the four urban wetlands was determined by running the software at patch level.

13.2.3 Water Quality

The water quality of selected water wetlands of both urban and urban fringe area in the study was measured at Environmental Microbiology Laboratory, icddr, b, Mohakhali, Dhaka. Descriptors (indicators of organic matter) of the oxygen status of urban wetland taken in the research are Chemical Oxygen Demand (COD) and

Biochemical Oxygen Demand (BOD). The nutrients that were considered in the research for the water quality analysis of the urban wetland are, Total nitrogen: TN. Total Suspended Solids: TSS test are conducted to determine the suspended solids in the water. Faecal coliforms, a subset of total coliform bacteria, are used as indicators of possible sewage contamination because they are commonly found in human and animal faeces (U.S. Environmental Protection Agency).

Faecal coliform tests were conducted to determine the faecal coliform bacteria which are the most common microbiological contaminants of natural waters. To make the sample of water collected from each water body as much representative as possible of the particular water body following procedure was followed. Firstly, a big bucket was fully soaked in the water of the lake to make the microbial condition as same as the water body. Secondly, water samples from different points both at the edge and middle of the lake were collected and mixed in that particular water bucket. Finally the water container supplied by the icddr was filled with the water from that bucket and supplied to Environmental Microbiology Laboratory, icddr for testing within 2 h of collection. The vegetal configurations at the edge of the water bodies in the study are also recorded.

13.2.4 Land Use

GIS land-use map of Dhaka city compiled by the RAJUK (Dhaka development Authority) was studied within the watersheds of the selected urban wetlands. The categories of land use designated in the maps are residential uses, mixed uses, commercial (offices and retails), industrial, recreational, slum, health facility, roads and water bodies. In this study a buffer zone of half a kilometre (0.5 km) was considered to study the direct impact of urban land use on water quality.

13.2.5 Urban Micro-climatic Measurement

For urban micro-climatic measurement, temperature profile within the half (0.5) km buffer zone created for urban land use around each urban wetland was created by direct spot measurement. Measurement campaign around each water body was conducted in between 12:00 and 15:00 as this is the hottest period of the day in Dhaka. Mean air temperature of those spot measurements was then calculated. Two air temperature reading one at 12:00 and the other at 15:00 by the meteorological station of the Dhaka city of the corresponding day of spot measurement campaign was collected. The average of these two reading is the mean regional air temperature in between 12:00. and 15:00. of the Dhaka city. The difference between the mean air temperature of the spot measurement around each water body and the mean regional air temperature of that particular day is then determined. This value is a good indicator of how hot the urban micro climate is.

Finally all the four parameters were correlated to find out if the overheated urban microclimate within a watershed deteriorates the urban water quality of the wetland by decreasing dissolved oxygen in the water. Urban wetlands with complex shape in its natural form can positively contribute to water quality while simultaneously moderating the negative effects of land use and increasing the cooling capacity of urban wetland (Hwang et al. 2007).

13.3 Results and Discussion

To determine the shape complexity of the urban wetland Fractal Dimension Index (FRAC) was calculated using Fragstat software (Table 13.1). From the FRAC value it is evident that Dhanmondi Lake has the most complex shape and Alubdi Lake has a comparatively simpler shape, as it is changing from its natural shape due to the earth filling.

The test results of the water quality of the selected urban wetlands are given on Table 13.2. From the water quality report it is evident that the quality of water at Dhanmondi Lake is best and Hatirjheel Lake is the worst. The quality of water at Alubdi Lake located at urban fringe are much closer to Dhanmondi Lake specially in terms of faecal coliform count although this water body is not protected like the other three. One of the reasons could be the presence of large amount of reed plants at the edge of this water body as shown in the Fig. 13.1. Reed plants are also present

Table 13.1 Fractal dimension index of the lake shape

Lake	Fractal dimension index (FRAC)
HatirJheel	1.1507
Banani	1.1599
Dhanmondi	1.2334
Alubdi	1.112

Table 13.2 Water quality report of the lake

Water quality parameters	Unit	Hatirjheel lake	Banani lake	Dhanmondi lake	Mirpur Alubdi lake
Faecal coliforms	CFU/100 mL	270,000	105,000	600	1,500
Chemical oxygen demand (COD)	mg/L	17.5	15	<3.0	12.5
Biological oxygen demand (BOD; 20° C)	mg/L	6	5	<2.0	4
Total nitrogen (TN)	mg/L	2.68	1.6	0.86	1.75
Total Suspended Solids (TSS)	mg/L	134	186	37	265



Fig. 13.1 Reed plants at the edge of the Alubdi lake

Table 13.3 Land use in percentage of total area with in half km buffer zone of the lake

Land use in percentage of the total area in the buffer zone	HatirJheel	Banani	Dhanmondi	Alubdi
Residential land use %	10.1	32.67	70.95	91.46
Mixed use land use %	2.53	0.01	7.92	0.001
Commercial land use %	1.32	0.0021	1.5	0.5
Industrial land use %	5.69	0	0	0
Health facility land use %	0.36	67.02	0	0
Road land use %	5	0.0147	18.48	2.21
Recreational land use %	0	0.002	1.13	0
Slum land use %	0	0	0.02	1.11
GraveYard land Use %	0	0.0001	0	0
Unknown land use %	74.99	0.2783	0	4.71

at Dhanmondi Lake both at the edge and under water although all types of reeds were cleared off during the time of development work of this lake. Those plants naturally grew back and helped to improve the water quality. In the other two lakes all the natural reeds were completely cleared off during the development work. Due to the better water quality there is aquatic life in Alubdi and Dhanmondi Lake. Some bird species like Kingfisher could be observed at the Alubdi Lake.

The result of the GIS land use map analysis of the Dhaka city within half km buffer zone around each lake are given below. The entire land use category is given in percentage of the total area (Table 13.3). It is clear from the result that Dhanmondi (70.95 %) and Alubdi (91.46 %) have mostly residential use around them whereas Hatirjheel (10.1 %) and Banani (32.67 %) have less residential use. Around

Table 13.4 Urban micro-climatic measurement around the lake

Lake	Temperature difference °C
HatirJheel	2.07
Banani	1.29
Dhanmondi	0.63
Alubdi	2.46

Hatirjheel Lake there is industrial land use (5.69 %) which other lakes do not have around them. A higher portion of health facilities are located around Banani Lake within the buffer zone.

All the average spot temperature measure around the lake in the study is above the air temperature reading by the meteorological station of the Dhaka city. Table 13.4 shows the temperature differences. Dhanmondi Lake has the lowest temperature difference whereas Alubdi lake has the highest temperature difference. Dhanmondi Lake has the highest level of vegetation around it and Alubdi Lake is almost devoid of shading trees. Although there is no hard pavement such as concrete around the Alubdi Lake the land fill around it is sand, which becomes much hotter in the day in comparison to natural soil and grass cover. HatirJheel Lake has the most hard pavement around it and is also devoid of shading trees.

It can be inferred from the result that shape complexity has a positive impact on the water quality as the lake with best water quality in the study is Dhanmondi Lake which has the most complex shape in terms of FRAC value (Table 13.5). Although the lake with the second best water quality, Alubdi Lake has the least complex shape among the four. This is due to constant change of the shape of Alubdi Lake due to human intervention by earth filling of the area of the lake.

The lake with the best water quality in the study, Dhanmondi Lake, has the minimum temperature difference with the regional temperature i.e. temperature from the meteorological department of Dhaka city. There could be several reasons behind the lower temperature difference such as the presence of large amount of vegetation, less hard paved areas and also the shape complexity. Again in this case Alubdi Lake has the second best water quality has having the highest temperature difference because of an absence of shade trees, sand instead of normal soil and grass cover around it due to land filling and also a change of its natural fractal shape due to earth filling.

Both the Dhanmondi and Alubdi Lakes are having mostly residential use around them which may have a positive impact on the water quality. One things to note is that human sewage flow into Dhanmondi Lake is stopped during the development process which is definitely helping to improve water quality. In case of unprotected Alubdi Lake, although human sewage together with animal excreta flows into the lake, the water quality is relatively good due to the presence of natural reed plants which are proven to have water purification capabilities. The highest reading of TSS in the Alubdi Lake is due to earth filling for residential use, which is also changing and decreasing its original shape.

Table 13.5 Co-relating the results of the analysis done for the lake

Lake	FRAC	Faecal coliforms CFU/100 mL	COD mg/L	BOD; 20° C) mg/L	TN mg/L	TSS	Temperature difference deg C	Residential land use %	Industrial land use %	Health facility land use %
Hatir Jheel	1.1507	270,000	17.5	6	2.68	134	2.07	10.1	5.69	0.36
Banani	1.1599	105,000	15	5	1.6	186	1.29	32.67	0	67.02
Dhanmondi	1.2334	600	<3.0	<2.0	0.86	37	0.63	70.95	0	0
Alubdi	1.112	1500	12.5	4	1.75	265	2.46	91.46	0	0

13.4 Limitations of the Study

There are several limitations of the study as given below:

- The number of lake in the study is relatively low; this is due to the high cost of water quality test in icddr, b, which is an internationally recognised organisation for its reliable testing quality. There should be more samples from the fringe areas of the lakes. Some lakes from the rural setting should also be included in the study.
- There was a lack of data logging instruments to log the temperature data at the same time on the same day around each lake. The author measured the spot temperature with Thermo-Hygrometer around different lakes on different days. However comparing the temperature difference with the data from the meteorological department is also a way to overcome the problem of not having enough data logging instruments, as this method has proven to be an effective way of measuring urban micro climatic temperature. This method is also used in previous research (Ahmed 1995).
- Simulation study with the help of ENVI-MET should be conducted to see urban micro climatic effect if the lake in the study has a simple and pure geometric shape.
- The natural reeds present in the Dhanmondi and Alubdi Lakes should be tested separately for the extent of their water purification capabilities with the help of REED Bed or Constructed Wetland.

13.5 Conclusions

The findings of this research would have the potential for use in urban wetland areas of Dhaka in the form of 'landscaped water parks' which besides water purification and micro-climatic cooling, will also serve purposes of leisure and have park amenities. Urban cooling in a growing energy crisis in the Dhaka city will be an effective way forward along with the supply of recycled urban waste water by natural means. A significant part of the urban wetland of Dhaka would be constructed to enhance the habitats for birds and fish, such as to establish a thriving ecosystem which would also enhance activities like bird watching. Such a wetland would also help in recharging groundwater which in turn reduces earthquake vulnerability.

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